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APPLICATION OF ENCODERS IN MISSILE AZIMUTH ALIGNMENT SYSTEMS

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APPLICATION OF ENCODERS IN MISSILE AZIMUTH ALIGNMENT SYSTEMS

by

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Redstone Arsenal, Alabama

(U) ABSTRACT

The use of shaft angle encoders in missile azimuth alignment systems is discussed. A brief resume of the characteristics of several encoders is presented with a discussion of the use of incremental encoders as a step toward increased system reliability.

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APPLICATION OF ENCODERS IN MISSILE AZIMUTH ALIGNMENT SYSTEMS

I. INTRODUCTION

The use of encoders in missile azimuth alignment systems has received considerable investigation by both industry and the services. Extremely accurate angle data acquisition is necessary in missile azimuth alignment and the shaft angle encoder has proven to be the most feasible component to provide this accuracy and resolution.

Very accurate angle data acquisition can be obtained manually through the use of theodolites. Since missile systems usually require a data computer to perform prelaunch computations, azimuth alignment operations can be automated if the data is supplied to the computer. Encoders have been attached to theodolites to provide digital data to the computer as a step toward automatic missile alignment. An accurate and reliable encoder-theodolite system can be used with a data computer to save time and eliminate human errors associated with manual readout and computation of angles. An automatic azimuth alignment system was developed for the PERSHING Missile System. This discussion primarily concerns the PERSHING system; however, the encoder investigation is applicable to missile systems in general.

II. BACKGROUND

The problem of encoder reliability is not only in the encoders. It is the complete encoder system including gray code to binary conversion and digital to analog conversion. The PERSHING automatic laying system used the following equipment:

1. A north seeking gyro with encoder to give the angle between north and a transfer theodolite.

2. A transfer theodolite with encoder to give the angle between the north seeking gyro and the missile heading.

3. An encoder located under the missile to give the amount of rotation of the missile after erection to turn to firing azimuth.

Each encoder contains a 16 channel optical disk read by a pulsed light source and 16 photo cells. Outputs from the photo cells were routed to 16 amplifiers mounted in the encoder housing. The 16 channel amplified signals provided a 16 bit gray code to the programmer test station by a cable. The 16 bit gray code was converted to a binary number and switched either to the basic computer or to a D to A conversion chassis. Digital to analog conversion was performed by a digital resolver network consisting of a relay ladder across multi-tap transformers used to supply voltages to a 3 speed resolver system. Analog information was readout or stored in a servo repeater which formed the other half of the 3 speed synchro resolver system. The servo repeater was also used to supply position information to the launcher motor through the laying chassis.

All angles turned were calculated by the basic computer by finding the difference between 2 full number readings of the encoder. The basic computer was programmed to calculate the arbitrary missile heading from the encoder readings and then calculate the angle the missile must be rotated to be on firing azimuth. After missile erection, the launcher encoder arbitrary full number was read and stored in the servo repeater. The difference between arbitrary azimuth and firing azimuth was added to the first launcher encoder reading and stored in the servo repeater. The missile was then rotated until the launcher encoder reading was the same number stored in the servo repeater.

As previously noted, all angles are calculated from 2 full number encoder readings. One approach bearing investigation is use of incremental encoders rather than full number encoders. The information required is the total angle turned. The advantage of using the incremental encoders is increased encoder reliability as well as decreased weight and size. An incremental encoder would provide a number of pulses depending on the size of the angle turned. The pulses would be counted and the resulting data used to rotate the missile to firing azimuth as before.

The Wayne-George Corporation has proposed an incremental encoder presented by their drawing number 2063-001. In this report they point out that the incremental encoder is a single track, or at most a double track, device while the direct reading encoder has 16 tracks requiring 16 concentric optical patterns on the disk, 16 detectors, 16 amplifiers, and the associated problems of each. An incremental encoder greatly reduces these problems and the accuracy and resolution achieved can be at least twice those of the direct reading encoder of the same diameter.

Choice of an encoder must include careful consideration of the use of the encoder in the missile system. For example, using an incremental encoder requires starting a pulse count from a zero position which may be a distinct disadvantage under some conditions. Minimum resolution considered for our application is a 16 bit encoder. This provides .1 mil resolution (20 sec arc).

III. INVESTIGATION

Encoder literature from various companies has been evaluated. The following is a brief resume of the characteristics of units made by those companies. This list is not to be considered an "encoder catalog" in any sense. This listing is merely an indication of the types of products from the literature available at the present time.

GUIDANCE CONTROLS CORPORATION

13 bit

Brush type

Full number readout

NORTHERN PRECISION LABORATORIES, INC.

13 bit

Full number readout

COMPUTER CONTROL COMPANY, INC.

16 bit

Optical with strobe pulse

Full number readout

LITTON SYSTEMS, INC.

13 bit

Brush type

Full number readout

TELECOMPUTING CORPORATION

Maximum 2000 counts per revolution

Magnetic reading head

Incremental

AUSTIN ELECTRONICS

12 bit maximum

Magnetic reading head

2 synchronous motor driven disks

Incremental

LIBRASCOPE

1024 counts per revolution

Brush type

Incremental

NORDEN

Norden produces the "Microgon" which has been used with some degree of success. This unit is basically a tone generator. A synchronous motor drives a cylindrical rotor incorporating two peripheral rows of serrations or teeth. The rotor revolves at a constant speed inside two matched stators, each having the same number of serrations on their inner circumferences. One of the stators is stationary and the other is connected to the input shaft. The variable capacitor action of the rotor and stators produces two electrical signals. The reference signal is produced by the fixed stator and the variable signal by the variable stator. These two signals are of equal frequency but the phase of the variable signal is shifted with respect to the reference signal by an amount proportional to the angle turned by the input shaft. The phase shift is then measured and encoded by an electronic package. Although extremely high resolution can be obtained, the associated electronics necessary to encode this phase relation appears to be quite elaborate.

BALDWIN

16 bit

Optical (either strobe pulse or incandescent)

Full number readout

This line of optical encoders is produced by AR&T Electronics, which is a subsidiary of the Baldwin Piano Company. In the optical encoder, this company probably makes the most accurate due to their computer control technique for their optical disk codes. The company capabilities indicate that they could produce accurate reliable encoders at a competitive cost. An incremental encoder with any special verification or orientation codes could be made at a minimum development cost due to their computer control optical disk techniques.

DYNAMICS RESEARCH CORPORATION

The "Theodosyn" is produced by DRC. This unit uses the Moire' effect of light pattern interference to produce 2^{16} pulses per revolution of the input shaft. These pulses would be counted by an up-down counter and the counter output would be the binary input to the computer. Their design would use a light source, optical system and light sensing cells in conjunction with a segmented disk attached to the input shaft. A "zero position" indication would be provided to give a verification pulse. This would be an additional light sensor to sense zero position of a mirror on the input shaft.

The unit will produce pulses from any position but the zero pulse can be used to compare the counter reading with zero reading of the encoder or to reset the counter to zero each time the input shaft is at zero.

The Theodosyn would be approximately seven inches in diameter by four inches in depth. This is not an "off the shelf" item. Their proposal indicates that the development cost and initial delivery may be prohibitive.

DATA TECH

The "Vernisyn" has been proposed by Data Tech. This unit could be developed in either a 3-inch-diameter pancake design or in a 1½-inch-diameter package using micro-circuitry at increased cost. The Vernisyn uses a synchronous motor driven disk, an input disk, and a stator. When energized, a magnetic pattern is created similar to an optical pattern on an incremental encoder. The unit uses the Moire' effect of magnetic pattern interference like Dynamic Research uses in the optical pattern of their optisyn. The main advantage of this unit is that a full number readout can be obtained without starting from a zero position due to the use of the motor driven disk. Shaft position may be read on command because a pulse count between input and reference is available for each disk revolution. Output is in the form of coarse and fine pulse trains on separate lines. By using the coarse and fine technique, 16 bit resolution is produced. One revolution of the input shaft produces 256 coarse count pulses and the Moire' vernier produces 256 fine counts for each coarse count, thus the resolution is 256^2. As in the Theodosyn, this unit is not an "off the shelf" item at this time. Price and delivery appear to be reasonable.

WAYNE-GEORGE CORPORATION

Wayne-George produces the absolute encoder previously used in the PERSHING system. They propose using their model RI-16 incremental encoder. This unit uses an incandescent light source in conjunction with a segmented disk and light sensors to provide pulses to a counter. Logic is provided for direction sensing and a zero pulse would be available for verification or counter reset. Operating life of this encoder would surpass their absolute encoder due to elimination of most of the light sensors and amplifiers.

BENDIX CORPORATION

Eclipse-Pioneer Division of Bendix Corporation proposes use of their 64 pole 2 speed resolver as a shaft angle encoder. Their unit uses a multi-pole structure to obtain an electrical equivalent of a 32 to 1 gear ratio between coarse and fine windings built into a 4-inch diameter unit. Final output would be basically the same as an incremental encoder. The 2 speed resolver would produce a phase shifted voltage proportional to the shaft rotation. An electronic package would be used to convert the phase shift to a time duration. The time duration would then be measured by gating pulses into a counter at constant rate. The counter therefore would receive a number of pulses porportional to the angle of rotation of the input shaft. The 2 speed resolver unit is cost competitive; however, the associated electronics appear to be quite elaborate. This system could probably be adapted to an A to D conversion where several transducers are used and the electronics can be time shared.

IV. CONCLUSION

In conclusion, it should be noted that development of an incremental design encoder will provide greatly increased reliability. This is not to say that an incremental encoder as such should be used as opposed to an absolute encoder, but to point out that an incremental type with the full number binary readout coming from a counter shows promise of increassing the overall reliability of the data processing system. This opinion is based on the difficulties encountered in the PERSHING System and the subsequent encoder characteristics and principles of design. This reliability would be brought about by the following:

1. Use of incandescent light source rather than high voltage strobe pulse, in the case of the optical encoder.

2. Reduction in complexity of the code disk.

3. Reduction in the number of components.

4. Reduction in the number of electrical conductors and connections.

5. Simplification of the power supply.

6. Reduction in the number of information channels to be processed.

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